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GB 1330714 A GB 1242404 A GB 1006362 A
GB 0941093 A GB 0656399 A

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(54) **Fire sensor using ultrasonic sound**

(57) A sensor 1 comprises drive electronics and a transducer 5 which emits ultrasound, and a second transducer 6 which receives the ultrasound via direct paths 7, and via indirect paths 8 by reflection from the surfaces 2 of volume in which the sensor is installed. Should a fire 3 occur in the volume, rising bubbles of warm air 4 refract some of the ultrasonic beams 9 changing their path lengths, and consequently the amplitude, frequency and phase of the ultrasound is disturbed. Receiving electronics derives a signal which varies as a function of this disturbance, and signal processing is carried out within a microcomputer to identify random and/or chaotic components which may be characteristic of the presence of a fire. The sensor may used in a sensitive low cost fire detector, and may be readily combined with an ultrasound motion sensor to also detect the presence of people.

GB 2 299 668 A

Figure 1

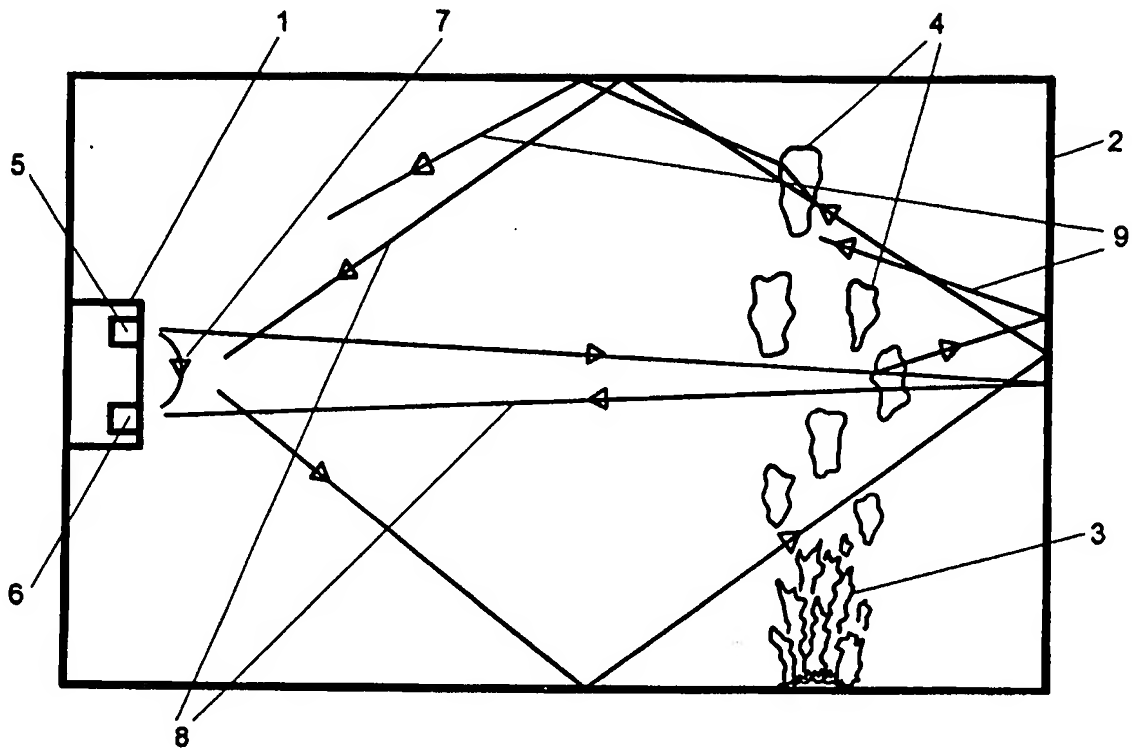


Figure 2

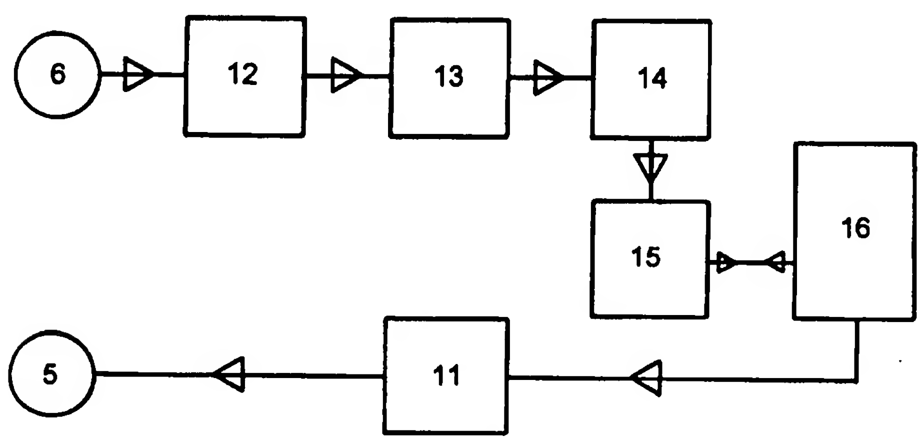
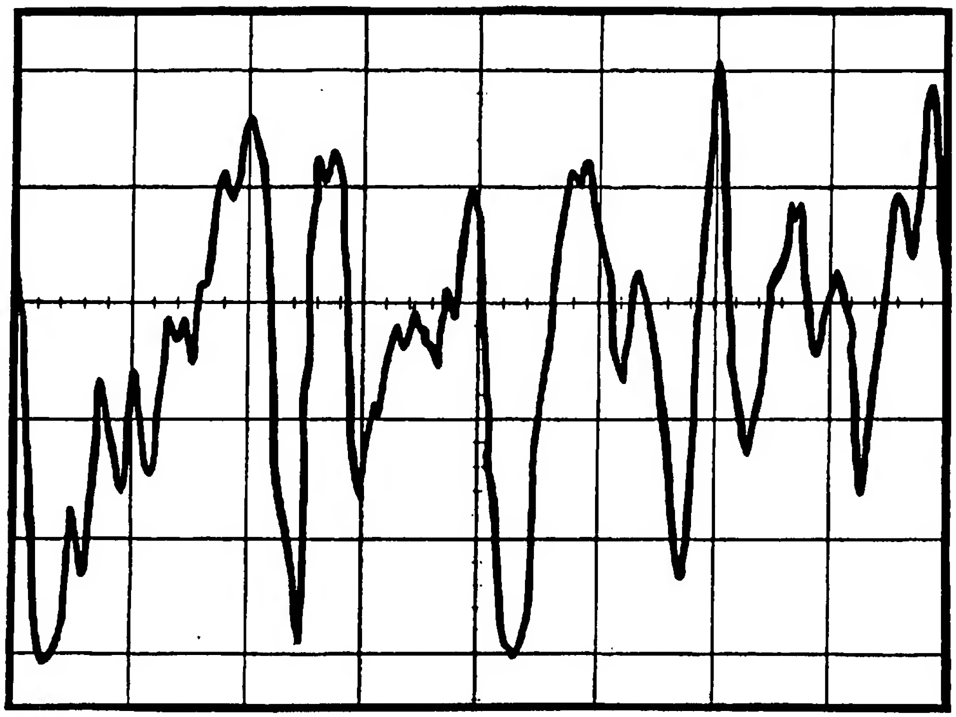


Figure 3



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HEAT SENSOR USING ULTRASONIC SOUND

This invention relates to an improved sensor suitable for the purpose of detecting the presence of hot gases resulting from a fire.

It is well known that sensing the heat given off by a fire is a very effective method for detecting fires. The most commonly used form of heat detector is the so called point heat detector. Modern forms of detector generally comprise an enclosure with a section which is relatively open to the ingress of air. This section contains a thermal sensor, usually a thermistor which has a relatively low thermal mass. Part of the airflow past the detector is sampled past the sensing element, which therefore senses a temperature relatively close to the air temperature. In some types of heat detector (so called 'fixed temperature' heat detectors) an alarm is given when the temperature of the element reaches a pre-set point. In other forms (so called 'rate of rise' heat detectors) the alarm temperature may be modified by a combination of thermal, electronic and/or software means to also take into account the rate of change of air temperature.

Point heat detectors are generally installed on the ceiling of a protected space. They depend on the physical transport hot gases from the seat of the fire to the detector. This is governed by the laws of natural convection, driven by the energy released in combustion. The effectiveness of this transport of hot gases to the detector is significantly affected by many factors. These include the ceiling height and profile, the overall geometry of the protected space, the presence of forced airflows, layers of warm air trapped near the ceiling, on the proximity of the source of combustion, and on the heat output. Because of the many transport factors, and the wide range in ambient temperatures which must be accommodated, point heat detectors cannot in practice be made too sensitive without running a high risk of false alarms, and they are generally only intended to detect fires at a fairly advanced stage of development, for example with a heat output greater than 100kW.

If correctly installed, point heat detectors can be effective in detecting fires. However, great care must be taken in the planning of the installation. This includes deciding on the detector spacings, and on the sensitivity grades which should be installed, this being dependent on the ceiling height and the normally expected maximum ambient temperature. Specifications for sensitivity grades are given in the European standard EN54:parts 5 and 8. Recommendations for their selection and installation of heat detectors are given in the British code of practice, BS5839:part 1, which includes a recommendation that the maximum area of coverage should be $50m^2$ for one detector.

A better form of heat detector would be one which could sense the presence of abnormal sources of heat anywhere within the entire volume of the protected space, which is more specific in its sensing mechanism than merely monitoring the temperature of the overall body of air in the volume, and which is more tolerant of the environmental and installation factors affecting point heat

detectors. Such a detector should be expected to achieve a higher level of sensitivity in practice, and would therefore be more amenable to be combined with other forms of fire sensor, for example a smoke sensor, in order to achieve a better overall performance in detecting fires. It is the object of the present invention to achieve such a sensor.

According to the present invention there is provided a sensor comprising a first transducer in conjunction with suitable electronic means for the emission of ultrasonic sound waves, and a second transducer in conjunction with suitable electronic means for the reception of the said ultrasonic sound waves, both transducers being disposed within the same air volume, characterised in that the electronic means associated with the second transducer provides an output signal which varies as a function of modifications in the amplitude, frequency and phase of the emitted sound waves by effects within the volume, and wherein the amplitude, frequency and/or phase of the said output signal is analysed by electronic and software means in order to identify random and/or chaotic components which may be characteristic of the presence of a fire.

The invention will now be described by way of example with reference to the accompanying drawing, in which:

- Figure 1 shows an overall application of a sensor within a volume to detect a fire;
- Figure 2 shows a block diagram of the main components of the sensor;
- Figure 3 shows typical sensor signals before signal processing, resulting from a free burning fire.

As shown schematically in Figure 1, a sensor unit 1 contains a tranducer 5 which emits ultrasonic sound waves into a volume. A transducer 6 receives the sound waves via direct paths 7, and via indirect paths 8 which are reflected from the surfaces 2 of the volume. If the emitted sound is at a constant frequency the volume is in effect filled with a standing wave, and all points in the volume may be monitored from any one point. The sensor could be mounted in any convenient position In practice high on the wall of a room is generally found to be convenient. The presence of a fire 3 results in rising bubbles of warm air 4, which interfere with certain of the indirect paths 9, causing some of the sound waves to be refracted at the density discontinuities between the warm air bubbles and the cooler mass of air. This results in variations in the lengths of the indirect paths 9.

The wavelength of 40kHz ultrasonic sound is about 8mm, significantly less than the size of the warm air bubbles. Considering a simplified model, the rising bubbles can be assumed to act as moving reflectors of sound waves emitted from a stationary source. As a result of the well known Doppler effect, the frequency is shifted for some of the sound waves received by the transducer 6 . For a source of frequency f, a reflector moving at a velocity v in line with a

stationary source and receiver, and where u is the speed of sound in air, the frequency shift (fDoppler) is given by the following equation:

$$fDoppler = (f * ((u / (u - 2v)) - 1)).$$

The velocity of the convection bubbles is typically less than $0.5ms^{-1}$. If the frequency of emission is a practically convenient value such as 40kHz, the shift in frequency will be less than 120Hz. The sensor therefore must be capable of resolving signals within a narrow pass band of up to ±120Hz around the emitted frequency.

As shown schematically in Figure 2 the emitting transducer 5 is driven by an electronic means 11 which provides an approximate square wave voltage output at a stable drive frequency of 40kHz. The electronic means 11 may be switched on and off by a microcomputer 16. The receiving transducer 6 is connected to an amplifier 12 with a broad pass band at the drive frequency, and having a voltage gain of approximately a factor of 20. This is followed by a unity gain linear half wave rectifier 13. The various frequency components in the received signal beat together and result in an output from the rectifier 13 of a signal at about 80kHz, the envelope of which is modulated with the difference frequencies. This is followed by an AC coupled filter amplifier 14, having a voltage gain of approximately a factor of 1000, and a pass band from approximately 20Hz to 150Hz. The output from this is taken to an analogue to digital convertor 15, which is associated with the microcomputer 16.

Figure 3 shows the typical output signal from the amplifier 14 resulting from a free burning fire with an output of approximately 10kW in a room of about $40m^3$ volume. The fire signature has a random or chaotic form, very characteristic of convective hot sources. Because of this nature it is possible to distinguish it from more constant sources of heat, for example fan blown space heaters, and also from other potential sources of disturbance such as moving objects.

It is preferable that the output signals are processed digitally within the microcomputer 16, since this involves the use of much less electronics hardware and hence less cost. In the preferred manifestation the signals are presented to the analogue to digital convertor 15 and conversions are carried out at regular intervals. The time interval between conversions should be less than 45% of the period of the highest frequency of interest, in order that this may be adequately resolved. In practice frequencies above 150Hz are found to be relatively unimportant, and an interval of approximately 3ms is found to be convenient, when using the 40kHz emission frequency as described.

It is also preferable that the method of signal processing does not require the use of a great deal of computer memory or processing power, since this tends to increase both the cost of the microcomputer and the power consumption of the sensor. A preferred and relatively simple method of digital signal processing involves the generation of a series of moving time averages from

the results of the analogue to digital conversions, calculated within different time domains. For example, if we assign the variable n0 to the result of each analogue to digital conversion, a time average n1, which adjusts with a time constant of approximately 12ms, may be calculated at 3ms intervals, as follows:

$$n1 = (0.25 \times n0) + (0.75 \times n1).$$

Similarly a time average n2, which adjusts with a time constant of approximately 50ms, may be calculated from n1 at 12ms intervals, as follows:

$$n2 = (0.25 \times n1) + (0.75 \times n2).$$

Similarly a time average n3, which adjusts with a time constant of approximately 200ms, may be calculated from n2 at 48ms intervals, as follows:

$$n3 = (0.25 \times n2) + (0.75 \times n3).$$

The signal amplitudes A0, A1, and A2, characteristic of 3 different frequency bands, may be calculated by summation of the absolute difference between the values of n0 and n1, n1 and n2, and n2 and n3, ie:

$$A0 = \quad ABS(n0 - n1);$$

$$A1 = \quad ABS(n1 - n2);$$

$$A2 = \quad ABS(n2 - n3).$$

The presence of a fire could be inferred from a signal having an amplitude greater than a given threshold, which is determined by the required sensitivity of the sensor, and by the fire detection application. However, this would be unreliable because of false alarms, resulting for example from moving objects. The processing is therefore adapted to detect signals having a random or chaotic nature. One simple preferred method is to reach the alarm decision only if signals are present which near simultaneously have amplitudes A0, A1, and A2 above given thresholds, a situation which would only tend to occur with signals which contain strong components in more than one frequency band.

The frequencies of the highest frequency main component within the signal may be calculated from the time intervals between the times at which the amplitudes of the sequence of values n0 crosses the time average n1, ie the times at which the difference between n0 and n1 change sign (the crossing points). Similarly the frequencies of main components at lower frequencies may be calculated from the time intervals between the crossing points of the time averaged values n1 and n2, and between the crossing points of the time averaged values n2 and n3. More sophisticated variants of this technique may be preferable to the simple method described, in order to minimise the effects

of random noise in the signal. These may include a fixed, or frequency variable threshold which must be exceeded before a crossing point is detected.

A second preferred method to indicate the presence of a fire is to analyse the signal frequencies for random or chaotic characteristics. For example a successive number of time intervals between crossing points may be mathmatically manipulated to determine both the mean value and the standard deviation, using well known equations. The presence of large values of standard deviation, in conjunction with large signal amplitudes, is a strong indicator of a fire.

According to a further feature of the invention, the emission of ultrasonic sound may be pulsed in order to save power. Since a stable ultrasonic standing wave is required within the volume for the sensing of heat, the pulse time must be sufficiently long for this to be present. In addition to this there is the time required for sampling and processing of the received signal. The settling time is dependent on the maximum dimensions of the volume. For example, for a room with a maximum linear dimension of 5m, the maximum path length from emitter to receiver is 10m assuming 1 reflection from the walls, and 20m assuming 3 reflections. Sound in air takes about 60ms to cover 20m. The minimum time required for sampling and processing is governed by the time required to sample the minimum freqency of interest. Frequencies below 20Hz are found to be relatively unimportant, which means that the sampling time must be greater than 50ms. In practice, it is found desirable to use a pulse time significantly longer than the minimum possible, and a time of approximately 300ms is found to be convenient. The maximum pulse repeat interval is determined by the acceptable time delay in detecting a fire. In the majority of applications a delay of 10s is found to be acceptable. It is of course possible for the controlling microcomputer 16 to reduce the pulse interval, or switch to continuous emission, if the sample resulting from a pulse indicates an abnormal condition.

The sensor arrangements described in the foregoing text could be constructed using various components, such as would be obvious to one skilled in the art of sensor design. The ultrasonic transducers could be those designed for operation at 40kHz, based on piezoelectric ceramic active elements, such as the MA40S3S and MA40S3R supplied by Murata. Simple horns could be added as part of the overall mechanical arrangement in order to concentrate and focus the ultrasonic energy. The microcomputer could conveniently be a Motorola MC68HC05B6, with the signal processing software coded in assembler language. The frequency at which the emitting transducer is driven should preferably be stable and free from jitter. This may be achieved by dividing down the output of a crystal oscillator by the desired amount. For example a 4.00MHz crystal could be divided down by a factor of 100 to output a stable 40kHz square wave with the aid of a suitably configured MC74HC390 integrated circuit, available from a number of suppliers. The stages of the receiver electronics may be readily constructed around 4 low cost operational

amplifiers such as are provided in a LM324 integrated circuit, available from a number of suppliers.

It will be understood that the principle of operation of the heat sensor is not fundamentally dependent on the exact details of the manifestation described, which is given by way of example only. The sensor could be realised with alternative transducer arrangements and frequencies, electronic circuitry, component specifications, or signal processing software. It will also be understood that elements, mechanical, electronic and/or software, in addition to those described in the foregoing text would be necessary to construct a practical fire detector, as would be known or obvious to one skilled in the art of fire detection systems design.

The manifestation described could be easily adapted with alternative signal processing to also detect moving bodies, primarily people. It will be obvious to one skilled in the design of motion sensors that the sensor heretofore described could be adapted to detect both fires and people.

CLAIMS

1 A sensor comprising a first transducer in conjunction with suitable electronic means for the emission of ultrasonic sound waves, and a second transducer in conjunction with suitable electronic means for the reception of the said ultrasonic sound waves, both transducers being disposed within the same air volume, characterised in that the electronic means associated with the second transducer provides an output signal which varies as a function of modifications in the amplitude, frequency and phase of the emitted sound waves by effects within the volume, and wherein the amplitude, frequency and/or phase of the said output signal is analysed by electronic and software means in order to identify random and/or chaotic components which may be characteristic of the presence of a fire.

2 A sensor according to claim 1 wherein the electronic means associated with the second transducer incorporates signal amplification, signal rectification followed by further signal amplication and frequency filtering in order to provide an output signal.

3 A sensor according to claim 1 or 2 wherein the means by which the said output signal is analysed is to carry out analogue to digital conversions of the signal at regular intervals, the interval being less than 45% of the period of the highest frequency of interest, and then to digitally signal process the data within a microcomputer.

4 A sensor according to claim 3 wherein the digital signal processing involves the generation of a series of averages from the results of the analogue to digital conversions, calculated within different time domains.

5 A sensor according to claim 4 wherein the signal amplitudes characteristic of certain frequencies are calculated by summation of the absolute differences between the results of the analogue to digital conversions and the fastest moving average, and/or by summation of absolute differences between different averages.

6 A sensor according to claim 4 wherein the dominant frequencies of various components within the signal are calculated from the time intervals between times at or near to which the difference between the results of the analogue to digital conversions and the fastest moving average changes in sign, and/or the times at or near to which the difference between different averages changes in sign.

7 A sensor according to any one of claims1 to 6 wherein the said transducers employ active elements manufactured from piezoelectric ceramics, and are designed to efficiently emit or receive sound waves at frequencies between 20kHz and 100kHz.

8 A sensor according to any one of claims 1 to 7 contained within a mechanical enclosure appropriate for mounting on the walls or ceiling of a volume to be protected, and configured as part of a system for the detection of fires, or of fires and persons.

9 A sensor substantially as herein described with reference to Figure 1 or Figure 2 of the accompanying drawing.

Amendments to the claims have been filed as follows

1 A sensor comprising a first transducer which emits ultrasonic sound into a volume, a second transducer which receives ultrasonic sound and associated electronic means incorporating signal amplification, signal rectification and frequency filtering to give a signal which varies in its amplitude, frequency and phase as a consequence of physical effects within the volume, characterised in that analogue to digital conversions are carried out on the said signal and wherein the resultant data is digitally processed using a microcomputer such as to identify the presence of components in the signal waveform which show a random or a chaotic nature characteristic of the presence of a fire.

2 A sensor according to claim 1 wherein those components of the said signal waveform which have a random or chaotic amplitude, frequency and/or phase are quantitatively analysed, so as to distinguish signals resulting from the presence of a fire from Doppler signals having a more constant amplitude, frequency and phase characteristic of objects moving within the volume.

3 A sensor according to claim 1 or claim 2 wherein the analogue to digital conversions are carried out at substantially regular intervals and the digital processing includes the generation of a series of averages from the results of the analogue to digital conversions, calculated within different time domains.

4 A sensor according to claim 3 wherein the amplitude of each signal characteristic of a different frequency is calculated by summation of the absolute differences between the results of the analogue to digital conversions and the fastest moving time average, or by summation of the absolute differences between two different time averages.

5 A sensor according to claim 3 wherein the dominant frequencies within the signal are calculated from the intervals between times at which the difference between the results of the analogue to digital conversions and the fastest moving time average changes in sign, and/or between times at which the difference between two time averages changes in sign.

6 A sensor according to claim 4 wherein the presence of a fire is inferred from there being present within a given time domain more than one signal having an amplitude which exceeds a given threshold, each signal being characteristic of a different frequency.

7 A sensor according to claim 5 wherein the presence of a fire is inferred from there being a substantial variation in the dominant signal frequencies within a given time domain.

8 A sensor according to claim 1 wherein the said transducers employ active elements manufactured from piezoelectric ceramics, which efficiently emit or receive sound at frequencies between 20kHz and 100kHz.

9 A sensor according to any one of claims 1 to 8 contained within an enclosure appropriate for mounting on the walls or ceiling of a volume to be protected, and configured as part of a system for the detection of fires.

10 A sensor substantially as herein described with reference to figure 1 or figure 2 of the accompanying drawing.

Patents Act 1977 Examiner's report to the Comptroller under Section 17 (The Search report)	Application number GB 9506787.2
Relevant Technical Fields (i) UK Cl (Ed.N) G1G (GPE, GPGX, GPW, GPX) (ii) Int Cl (Ed.6) G08B 17/00	Search Examiner D SUMMERHAYES
	Date of completion of Search 15 JUNE 1995
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii) ONLINE: WPI	Documents considered relevant following a search in respect of Claims :- 1-9

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Category	Identity of document and relevant passages		Relevant to claim(s)
X	GB 1330714	(MOSS) see particularly page 1 lines 71-75	1, 8 at least
X	GB 1242404	(EVERITT) see particularly page 3 lines 78-93	1, 8 at least
X	GB 1006362	(CLARK)	1, 8 at least
X	GB 941093	(E A LTD) see particularly page 2 lines 71-124	1, 8 at least
X	GB 656399	(CHARLIN) see particularly page 1 lines 9-12	1, 8 at least

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